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Changes in the flora of Thoreau's Concord

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ABSTRACT

To determine the effectiveness of conservation efforts, scientists and land managers must evaluate the ability of conservation areas to protect biological diversity. The historic town of Concord, Massachusetts, home of the philosopher and naturalist Henry David Thoreau, provides a unique opportunity to examine how well conservation areas preserve biodiversity in a suburban landscape. About 35% of total land area in the town has been protected, and botanists, including Thoreau, have surveyed plants in Concord five times over the last 170 years. We spent 5 years (2003–2007) re-surveying a subset of Concord's flora for species presence and abundance. Of the species seen by Thoreau in the mid-19th century in Concord, we could not locate 27%, and an additional 36% persist in one or two populations where they are vulnerable to local extinction. Most species losses appear to have occurred in the past three to four decades. Certain groups, such as orchids, have shown particularly severe losses. More native species are declining in abundance than are increasing. Non-native species represent an increasing percentage of the flora, with many increasing in abundance. The flora has experienced a net loss of species over the past four decades, with 82 species gained and 236 species missing. Because many species are rare on a local scale, persisting as one or two small populations, local extinctions will likely continue in coming decades. Habitat management, primarily to prevent tree establishment, appears to have allowed many rare species of open habitats to persist and recover. Active management of existing sites will likely be the key to protecting the species diversity of the Concord flora and maintaining the living connection to the writings of Thoreau.

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1. Introduction

One priority of conservation biology is to determine how effectively protected areas preserve biodiversity. Many studies have examined whether biodiversity is adequately represented in protected areas at a single point in time (e.g., Cowling and Pressey, 2003; Riemann and Ezcurra, 2005). Other studies have examined how protected areas mitigate human impacts, which presumably correlates with biodiversity (e.g., Bruner et al., 2001; DeFries et al., 2005). However, relatively few studies have examined changes in biodiversity over time as a method

of testing the effectiveness of protected areas. Those that have are limited to locations that have been surveyed or collected heavily for herbarium or museum specimens in the past. Such repeated surveys of conservation areas have often documented significant changes in species abundance over time despite protection efforts (Robinson et al., 1994; Drayton and Primack, 1996; Leach and Givnish, 1996; Stöcklin and Fischer, 1999; Lienert et al., 2002; DeCandido, 2004).

Here we examine the effectiveness of protected areas in Concord, Massachusetts. Botanists have surveyed the flora of Concord five times in the past 170 years. We believe that

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this makes Concord one of the most extensively botanized locations in North America, and possibly the world. The town of Concord also has a strong conservation tradition. Over one-third of the town's land has some degree of protection.

Much of this botanical and conservation tradition is due to the influence of Henry David Thoreau, the famous philosopher and naturalist who worked in Concord during the 19th century. Thoreau wrote extensively about the natural history and botany of Concord, recording observations in his journals and in books such as *Walden*. He is often considered the founder of the American environmental movement because of his eloquent pleas to value and protect wild nature. He recognized that Concord was changing even in his own time, and that many of the species observed there in the past were no longer present. He laments this loss in an eloquent passage:

Primitive Nature is the most interesting to me. I take infinite pains to know all of the phenomena of the spring, for instance, thinking that I have the entire poem, and then to my chagrin, I hear that it is but an imperfect copy that I possess and have read, that my ancestors have torn out many of the first leaves and grandest passages and mutilated it in many places. I should not like to think that some demigod had come before me and picked out some of the best stars. I wish to know an entire heaven and an entire earth. (Thoreau's Journals, March 23, 1856)

The pattern of development from rural to suburban in Concord has occurred over much of the United States. Suburban areas often contain many unique species and habitats, with great value for biodiversity and education. Many people interact with nature only in such suburban settings. Moreover, the various protected areas in most suburban towns in the United States, like Concord, lack coordinated plans to conserve biodiversity, although that is one of the implicit goals of the protected areas. For these reasons, we need to know how effective suburban protected areas are at preserving species. Species protection is especially important for Concord because it enables people to establish a living connection with species mentioned in Thoreau's writings. The goal of preserving the species and habitats observed by Thoreau is a frequent topic in environmental discussions in Concord today. The need to protect the biodiversity of Concord is also a national issue, as Thoreau's *Walden* remains widely read today by both students and citizens, more than 140 years since his death.

The purpose of this study is threefold. First, are plant species that Thoreau and other botanists observed in Concord still present? Second, have the establishment of protected areas allowed native species to persist in Concord? And lastly, is it possible to predict how the flora of Concord will persist in the future? To date, we know of no other study that has examined, in such detail, the effectiveness of protected areas in the suburban United States, a rapidly growing segment of the country.

2. Methods

2.1. Study site

Concord is a town 31 km west of Boston, Massachusetts, comprising 67 km². The landscape includes forested hills,

swamps, rivers and river meadows, ponds, bogs, and fields, including pastures, cultivated fields, athletic fields, and lawns. In Thoreau's lifetime (1817–1862), Concord had a mixture of industry, residential areas, agriculture and forestry, though agriculture was already in decline. Concord is a now suburb of Boston, with only a few farms left in a forested landscape intermixed with residential neighborhoods, business districts, and light industry. From studies of land use patterns, pictures, and past descriptions, it is clear that cultivated fields, pastures, wood lots, and river meadows were more common in Thoreau's Concord than in the modern town (Gross, 1982; Foster, 1999, 2002). Major features of the landscape are three rivers, a commuter railroad and a four-lane highway.

Concord has an extensive and diverse set of protected areas (Fig. 1), including Walden Pond State Park, Minute Man National Historical Park, Great Meadows National Wildlife Refuge, Concord town lands, and private conservation land. These protected lands, amounting to 35% of the total area (Concord, 2005), vary in their reasons for establishment and their current management. Another 27% of land is undeveloped, parcels of which are currently targeted for conservation efforts, including farms, lands owned by the Massachusetts prison system, public and private school lands, private clubs, and individually owned tracts.

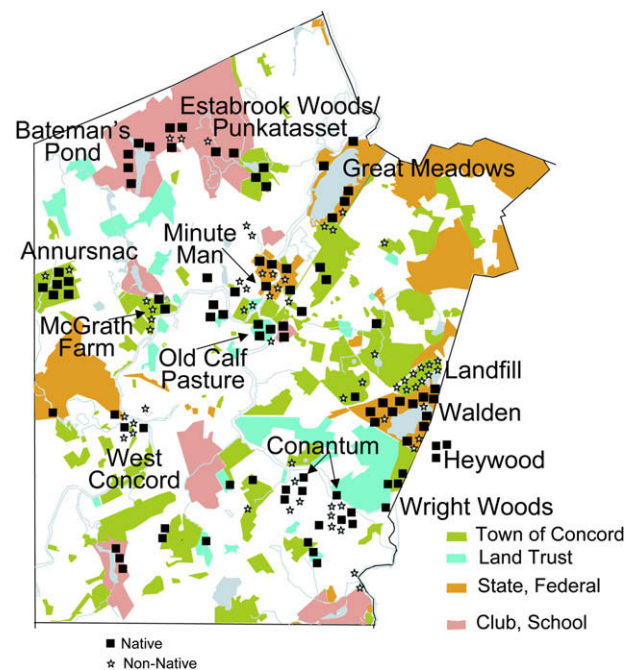


Fig. 1 – A map of Concord, Massachusetts, showing the approximate locations of species currently rare; i.e., known from only one site in the town. Native species are shown as squares, and non-native species are shown as stars. Protected lands are shaded, and general categories of ownership are shown. Major sites for rare species are labeled. For sites with many rare species, such as Walden Pond, the symbols are spread out beyond their actual distribution.

2.2. The Concord flora

Five people have surveyed the Concord flora: Edward Jarvis (1803–1889), Henry David Thoreau (1817–1862), Minot Pratt (1805–1878), Alfred Hosmer (1851–1903) and Richard Eaton (1890–1976). These individuals were part of a community who walked around Concord, studied its flora, and shared observations of species and localities. This informal community of Concord naturalists continues today.

Concord's plants are first known from Jarvis' published list of a partial flora, based on fieldwork from 1823 to 1837 (Chapin, 1994). In our study, we use 347 species that he noted.

Thoreau made lists of the flowering times of species of Concord plants from 1851 to 1858, from which he intended to describe Concord's seasons (B. Dean, personal communication). He did not complete this work before his death. Thoreau also made observations of Concord plants in his journals (Angelo, 1984). We used both the list of flowering times and the journal entries to compile a list of 578 wild (both native and non-native) species that Thoreau observed in Concord.

Alfred Hosmer, a local shopkeeper, made detailed observations on the first flowering times and abundance of 479 wild plant species in Concord from 1888 to 1902 (Hosmer, 1878–1903). He never wrote about his observations. He may have carried out the work in part out of admiration for Thoreau.

Hosmer, and to some extent Thoreau, made only limited observations of plants with inconspicuous flowers, such as grasses, sedges, rushes, many wind-pollinated trees, and many aquatic plants. As a result, we excluded these groups, including non-flowering vascular plants, from our analysis for all of the botanists. We also excluded certain plant species that were not possible to identify accurately in the field. In total, we examined about two-thirds of the Concord flora. Throughout this paper, when we refer to the flora of Concord, we are speaking of this subset of species.

Minot Pratt's observations overlap those of Thoreau and Hosmer, so we have not analyzed his plant list separately. Later in the paper, however, we discuss his practice of introducing new plants into Concord.

Richard Eaton recorded the most comprehensive flora of Concord (Eaton, 1974). His flora was based on decades of fieldwork extending from the 1920s to the early 1960s, and included only those species that were growing spontaneously and not just in cultivation. Eaton documented a flora of 723 species that occurred in Concord, excluding the groups of species noted above which constitute another 428 species that we did not analyze. His list is larger than those of Thoreau and Hosmer because he had a greater knowledge of taxonomy allowing him to distinguish similar species. Eaton and we relied on Fernald (1950) for plant names.

We compiled our list of species based on four years of intensive field investigation (2003–2006) and occasional visits in 2007. From April to September, we searched Concord 1–3 days per week, seeking out places where rare plants might occur. We asked local naturalists where we might see plants from Eaton's flora that we had not yet observed. We also examined maps of Concord and systematically searched locations that we had not previously visited. On field days, we typically had two field groups, often with two people in each

group. Our fieldwork focused on protected lands, as these constitute the largest amount of undeveloped land in Concord and have many known locations of rare species. With few exceptions, we were also able to search privately owned lands. While doing this fieldwork, we also recorded the flowering times of plant species in Concord, and compared these with flowering times recorded by Thoreau and Hosmer (Miller-Rushing and Primack, 2008; Miller-Rushing et al., 2008; Willis et al., 2008).

We assessed species abundance in Concord, as this has been shown to be a predictor of species persistence over time (Lavergne et al., 2006; Walker and Preston, 2006). Eaton and Hosmer used many terms to describe species abundance, without defining them quantitatively. We aggregated their terms into two categories: "common" and "uncommon." For our own observations, we defined "common" species as those having three or more populations in Concord, and "uncommon" as those having only one or two populations in Concord. We further subdivided the "uncommon" category into species that are rare (occur in only one place) or infrequent (occur in two places). Species are also listed as very rare if we could locate only 2–10 individuals and extremely rare if we were able to locate only a single individual. It is possible that certain species may have been classified differently by Eaton, Hosmer and us. For example if a species occurred in three populations, all with few individuals, Eaton might have classified it as uncommon, but we would classify it as common. Although such problems in classification certainly occur, the number of species affected is probably small in comparison to the total number of species in the study. The full data set is available through Boston University (<http://people.bu.edu/primack/>).

Because most of our data were categorical, we primarily used Pearson's chi-square test to test for relationships between explanatory and response variables. When appropriate, we also used linear regression to test for changes over time. We considered results where $P < 0.05$ to be statistically significant.

3. Results

3.1. Species lost

Of 347 species seen by Jarvis, 20% are no longer found in Concord (Table 1). Of 578 species that Thoreau noted, 27% are no longer found in Concord, 15% are rare (i.e., are currently only found as a single population), and 21% are infrequent, occurring in only two populations. The figures are similar for Hosmer; of the 479 species observed by Hosmer, 24% are no longer present, 14% are rare, and 22% are infrequent. Of Eaton's more comprehensive and recent list of 723 species, 30% are no longer found in Concord, 14% currently occur as a single population, and 20% are now infrequent (Table 1). The proportion of species that were lost or became rare or infrequent is independent of observer (i.e., among Jarvis, Thoreau, Hosmer, and Eaton), as determined by a chi-square test ($\chi^2 = 3.88$, $df = 4$, $P = 0.423$).

Of the species that Thoreau observed, 90 species are now rare, with 23 very rare and nine with just one individual. Of 106 species listed by Eaton that are currently rare, 27 are very

Table 1 – Summary of the floras of Concord, Massachusetts collected by various botanists.

	Jarvis	Thoreau	Hosmer	Eaton	Present study
Date of flora	1837	1861	1902	1974	2007
Number of species recorded	347	578	479	723	589
Percent of species missing in 2007	20%	27%	24%	30%	
Percent of flora that was native	80%	79%	75%	68%	61%

rare, with populations of 2–10 individuals. A further 11 species are extremely rare with just a single individual, including formerly common species, such as the Canada lily (*Lilium canadense*).

Most species losses appear to have occurred in the four decades since Eaton carried out his final fieldwork. Of 744 species that Eaton listed as occurring in Concord during the 19th and 20th centuries, he listed only 21 species as presumably extirpated, or locally extinct at the time of his flora. This is a rate of loss of 1.8 species per decade. In contrast, we could not locate 236 of the remaining species in 2003–2007, a significant difference ($X^2 = 223.58$, $df = 2$, $P < 0.001$); this rate of loss is around 59 species per decade. The rate of species loss is more than 30 times greater over the past three decades than in the previous period. In effect, few species disappeared from Concord between the periods when Jarvis, Thoreau, Hosmer and Eaton worked, but one-third of Concord’s plants have apparently been lost since the time of Eaton’s flora. This pattern of a slow loss of species up until around 1974, followed by a rapid loss of species may be related to a rapid increase in the number of residents in Concord between 1950 and 1970, although the relationship is only suggestive (Fig. 2).

Orchids have always been of great interest to botanists. Eaton recorded 21 native orchid species, with one species possibly being extirpated. Despite intensive searching, we located only eight of these species, with six of these being rare. For the aquatic genus *Utricularia* (bladderworts), a sepa-

rate group of plants with colorful flowers and insectivorous morphology, Eaton listed eight species. However, we could only locate one common species, common bladderwort (*Utricularia vulgaris*), and one rare species, humped bladderwort (*Utricularia gibba*).

Another notably absent group is the mountain mints (*Pycnanthemum*), which typically grow in fields and woods. Eaton’s flora records six species, and Thoreau noted four species. However, we did not see even one plant of this group.

3.2. Changes in species abundance

For species that Eaton listed as common, 57% are still common, 11% are locally extinct, 9% are rare, and the remaining 23% are infrequent (with two populations). In contrast, for species that Eaton listed as uncommon, only 12% are now common, 20% are rare, 18% are infrequent, and 50% are now locally extinct. When we categorized each species as changing in abundance (to either common or uncommon), remaining relatively stable, or going locally extinct, we found that there was a significant difference between the species that Eaton listed as common and those he listed as uncommon ($X^2 = 138.41$, $df = 2$, $P < 0.001$). In short, species that were uncommon in the past were likely to go extinct, whereas species that were common in the past were likely to remain common or at least not go extinct. Also, far more species have declined in abundance than have increased.

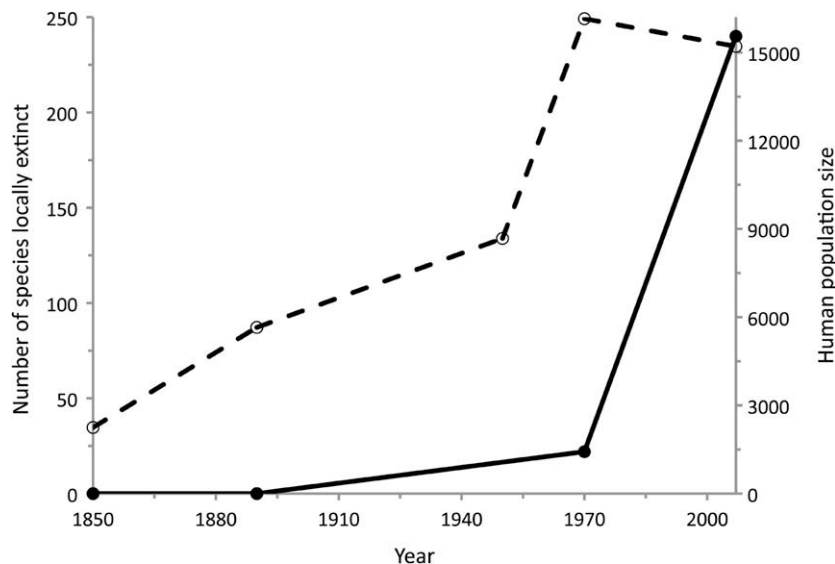


Fig. 2 – Changes in the number of species that have been lost from Concord (solid circles and line) and the number of residents in the town (open circles and dashed line) over time. Data on population size come from various unpublished reports in the special collections of the Concord Free Public Library.

Although Thoreau did not note the plants' abundance, we can assume that the abundance of species Hosmer noted just 30–40 years later resembled what was present in Thoreau's time. Land use change in the area was relatively small during this time compared to later changes (Foster, 2002). We also know that the community of local botanists during that time often shared localities for rare species and species of special interest (Eaton, 1974). Thus, it is likely that Hosmer knew of the sites that Thoreau observed through local naturalists whose lives overlapped with theirs. Of the 578 species observed by Thoreau, Hosmer reported the abundance of 428 species. Of these, Hosmer reported that 342 species were common and 86 were uncommon. Of the common species in Hosmer and Thoreau's time, 73% were still common, 27% were uncommon, and none were locally extinct as of 1974. In contrast, 33% are now rare or infrequent and 18% are extinct, a significant change over just 33 years ($X^2 = 80.24$, $df = 2$, $P < 0.001$). Of the uncommon species in Hosmer and Thoreau's time, 76% were rare or infrequent in 1974, 7% were locally extinct and 17% had become common; in contrast, 45% are now rare or infrequent, 44% are now extinct, and 10% are now common. Again, the change between Eaton's time (1974) and the present was significant ($X^2 = 31.27$, $df = 2$, $P < 0.001$). When we categorized each species as changing in abundance or remaining stable, the change in species abundance from 1974 to 2007 (33 years, over which 109 species changed in abundance and 313 did not) was approximately the same as the change from 1861 to 1974 (113 years, over which 113 species changed in abundance and 315 did not) ($X^2 = 0.01$, $df = 1$, $P = 0.911$). However, significantly more species went extinct between 1974 and 2007 (93 of 422) than did between 1861 and 1974 (6 of 428) ($X^2 = 85.94$, $df = 1$, $P < 0.001$). Also, just as with Eaton's observations, species that were rare in Hosmer's and Thoreau's time were likely to go extinct, whereas common species were much less likely to go extinct.

3.3. New species

We observed 82 "new" species, that is, species that Eaton did not record as occurring in the wild in Concord. Most are species that form self-sustaining populations from seed, or are spreading vegetatively. Hosmer and Thoreau noted several of these species, which were probably grown in cultivation at that time but have since become established on their own. Escaped ornamental plants, such as longflower tobacco (*Nicotiana longiflora*) and garden lupine (*Lupinus polyphyllus*), represent the largest group of new species. However, new weed species and native species not previously reported from Concord also appear on the list of new species. The Concord landfill, a restored open meadow habitat with exposed and unstable surfaces, has the largest number of new species (Fig. 1).

Most new species (45 species) are rare. Fourteen of the new species are very rare or extremely rare, indicating their tenuous presence in Concord. In contrast, 17 of the new species are now common, reflecting rapid changes that have occurred in the last 33 years. For example, bird's foot trefoil (*Lotus corniculatus*) grows abundantly at many locations, including Walden Pond, although Eaton did not observe it. The remaining 20 species are infrequent. The most serious invasive species in Concord today, such as garlic mustard (*Alliaria petiolata*), black swallow-

wort (*Cynanchum louiseae*), glossy buckthorn (*Frangula alnus*), and Morrow's honeysuckle (*Lonicera morrowii*), were already present in Eaton's flora, and are not listed as new species.

3.4. Native versus non-native

As native species have gone extinct and non-native species have arrived, the percentage of native plants in the flora has declined. Native species are considered by Eaton (1974) and us as those that occurred naturally in Concord and the surrounding towns at the time of European arrival. The non-native plants are mainly agricultural weeds, plants of disturbed habitats, and escaped garden ornamentals. In the 19th century, native species were 80% of the flora of Jarvis, 79% for Thoreau, and 75% for Hosmer. However, in the 1970s, natives made up only 68% of Eaton's flora (Table 1). By 2007, the native species were only 61% of the flora, representing a significant decline in percentage of native species over time as determined by linear regression (slope = $-1.1\%/decade$, $P = 0.002$, $R^2 = 0.97$).

This decline in the percentage of native species appears likely to continue for five reasons. First, 82% of the species that declined in abundance in the decades since the work of Eaton were native species, significantly more than the 68% of the total flora that were native ($X^2 = 8.82$, $df = 1$, $P = 0.003$). Second, of those species that increased in abundance, only 39% were native species, significantly less than the proportion of native species in the total flora ($X^2 = 13.54$, $df = 1$, $P < 0.001$). Third, of those species that were new to Concord, only 23% were native to Concord and neighboring towns, again fewer than the proportion of native species in the flora ($X^2 = 62.20$, $df = 1$, $P < 0.001$). Fourth, the land disturbances currently occurring in Concord continue to favor non-native species. And fifth, gardening activities continue to bring new plant species into the town.

3.5. Habitat types

To examine the effects of habitat types on the composition of the flora, we assigned species to one of four categories: forest, grasslands and fields, roadsides, and wetlands. When species occurred in two or more habitats, we assigned them to the habitat where the species was observed most frequently by Eaton and in our own fieldwork. Of the species listed by Eaton, the percentage occurrence was 26% in forest, 30% in grasslands, 19% in roadsides, and 25% in wetlands. Species went extinct from 1974 to the present roughly in proportion to their percentage of the flora, with 26–34% of species lost from each habitat type ($X^2 = 1.32$, $df = 3$, $P = 0.724$). This result is striking because the area of each habitat type in Concord changed differently. For example, in 1850 forests covered approximately 10% of the land area in Concord and grasslands covered around 50% (Gross, 1982; Whitney and Davis, unpublished). By 1975, however, forest coverage had increased to 50% of Concord's land area while grassland coverage had declined to 4%, similar to the coverage of each habitat type today. Thus, in each habitat, there were more species lost than gained, resulting in a net loss of species over time, regardless of whether the area of that habitat increased or decreased over time (Table 2).

Table 2 – Changes in the flora of Concord, Massachusetts by habitat. Number of species from Eaton refers to the species listed in Eaton's flora (1974). Numbers of species missing and new are comparisons between species found 2003–2007 and those listed in Eaton (1974).

Habitat	Number of species from Eaton	Number of species missing in 2007	Percent missing in 2007	Number of new species in 2007	Percent new of original number
Forest	192	57	30	17	9
Grasslands and fields	216	57	26	35	16
Roadside	135	41	30	22	16
Wetlands and aquatics	185	62	34	8	4

New species did not occur equally in each of the habitat types ($X^2 = 15.13$, $df = 3$, $P = 0.002$). Fully 70% of the new species were from the grassland and roadside habitats, even though these habitats accounted for only 49% of the species in Eaton's flora and the area of grasslands in Concord has declined over the past 150 years (Gross, 1982; Foster, 2002; Whitney and Davis, unpublished). Wetlands showed the least gain in new species. Overall, forests and wetlands are showing the greatest net loss of species, despite the great increase in forest area and strong legal protection accorded to wetlands.

3.6. Hotspots

Eaton (1974) listed certain localities of "exceptional botanical interest," where he observed many rare and unusual species. These places included rocky outcrops, clamshell deposits, rivers, river meadows, and sphagnum bogs. Certain unusual habitats, such as limestone outcrops in Conantum and the Estabrook Woods, and pond edges at Bateman's Pond and Walden Pond, still have concentrations of rare species (Fig. 1). Both before and since Eaton's time, many of these habitats changed considerably, altering the plants that occur in these places. For example, the Clamshell Bluff has been almost completely destroyed to provide space for a hospital, residential housing, and major highway. Also, river meadows have changed since Thoreau's time, when they were mown for hay and filled with wildflowers. The meadows are no longer mowed and have mostly become swamp forests or dominated by stands of exotic species. Native river meadow species now occur in a few mowed places, such as the Old Calf Pasture, which is actively managed to protect the coast violet (*Viola brittoniana*), a state threatened species, and Minute Man National Historical Park, which is managed to maintain meadows along the river.

In addition to Eaton's key localities, we have identified other concentrations of rare species and new species, with many being non-native (Fig. 1). For example, the West Concord train station and business area has many rare non-native species, such as leafy spurge (*Euphorbia esula*) and viper's bugloss (*Echium vulgare*). In addition, the Concord landfill has numerous species that occur there and nowhere else, including many escaped ornamental plants. Some of these species may have arrived at the site in the soil used for capping the site when dumping stopped.

3.7. Deliberate introductions

Between 1860 and 1875, Minot Pratt, apparently as a personal hobby, tried to introduce additional species into Concord from

elsewhere in the northeastern United States. He planted species in sites that were comparable to their native locations, carefully tending them for years (Eaton, 1974). Of the 60 species that Pratt attempted to establish (not including mosses, ferns and gymnosperms), Hosmer noted that 17 were still present in 1899, 24 years later (Hosmer, 1899).

Of the 10 of Pratt's species that we were able to locate in the wild, six were species that Hosmer said were still persisting, and four were species that Hosmer said no longer occurred. Because certain of these species were common ornamentals, such as lily-of-the-valley (*Convallaria majalis*), they were probably reintroduced after Pratt. If we assume that two to four of the species that Pratt planted are still present as a result of his efforts, then the success rate is quite low, somewhere between 3% and 7%.

4. Discussion

Federal agencies, the Massachusetts state government, the town of Concord, a university, and private schools and conservation organizations have established and now manage a network of protected areas that covers one-third of the Concord's area. These organizations had different reasons for establishing these protected areas, and they now have different management goals. Some try to maintain historically open landscapes, while others focus on maintaining wildlife habitat, protecting endangered species, controlling exotic invasive species, highlighting the life work of Thoreau, or providing space for education and public recreation. While there is no overall plan in which these organizations work together to protect Concord's biodiversity, there is an expectation that their goals are complementary and contribute to the preservation of biodiversity in Concord.

How effective are these land conservation programs at protecting Concord's plant diversity? Our comparison of the observations of Jarvis, Thoreau, and Hosmer with the modern flora shows that approximately 25% of the plants present in the 19th century can no longer be found in Concord. Depending on one's perspective, this result is either encouraging or discouraging. Even after 150 years, 73% of the species that Thoreau observed in Concord still occur there. On the other hand, despite the extensive conservation activities found in Concord, we cannot find 27% of the species.

Of the species that Eaton recorded in his flora 1974, 30% could not be found today. Thus, it appears that a higher proportion of species have disappeared in the last three to four decades than during the 150 previous years, a counterintuitive result. It is likely that many of the species that declined between the 1850s and the 1970s disappeared completely

from the local flora in the past three to four decades as a result of recent changes (see below). However, other factors, such as the amount of effort of each botanist, could have contributed to this pattern. Eaton worked intensively with a goal of creating a complete flora, whereas Thoreau and Hosmer created their lists incidental to other activities, recording flowering times in particular. Consequently, Eaton's list contains species that are rare or transient in occurrence. Such species recorded by Eaton may have not been noticed or recorded by previous botanists, and might be especially vulnerable to local extinction.

Thoreau, Hosmer and Eaton carried out their botanical investigations over a longer period than we did. Also, perhaps they knew the locations of plants better than we did. It is possible we missed certain species because they were only evident in certain years, or were difficult to detect (Kéry, 2004; Kéry et al., 2006). This would tend to inflate our estimate of the local rate of extinction. Nevertheless, we believe that the number of such overlooked species was small. We spent several days per week for 5 years examining the flora. We consulted Thoreau's, Hosmer's, and Eaton's notes and interviewed local botanists for locations of rare species. We also had more people in the field with us on any given day than did previous botanists. Undoubtedly, our investigation would have benefited from further fieldwork. However, we believe that further efforts would only change the numbers to a small degree and not affect our overall conclusions. Even if some of the species we list as locally extinct still persist as inconspicuous, non-flowering individuals or small populations, it is clear that the decline of species is dramatic, and that the rate of species loss from Concord has increased since the time of Eaton's flora in the 1970s. An increase in local extinction rates in recent decades has also been noted in botanical surveys carried out in the United Kingdom (Walker, 2003; Walker and Preston, 2006), though the increases have not been as dramatic as what we observed in Concord.

Our results show that the Concord flora is changing. Far more species are declining in abundance than are increasing. Most declining species are native species. In turn, most new and increasing species are non-native species, resulting in a flora with a higher proportion of non-native species. While aquatic exotics, such as Carolina fanwort (*Cabomba caroliniana*) and water chestnut (*Trapa natans*), have dominated certain wetlands since Eaton's times, invasive species on land seem to be a more recent problem. Many localities are now dominated by such invasive species as garlic mustard (*Alliaria officinalis*), glossy buckthorn (*Frangula alnus*), Asiatic bitter-sweet (*Celastrus orientalis*), and Morrow's honeysuckle (*L. morrowii*).

It is not obvious which factors are most responsible for the change in the Concord flora. One possibility is the large-scale abandonment of farming, grazing, mowing, and logging, and simultaneous increases in development. Farming, grazing, mowing, and logging kept the landscape relatively open and allowed species of open habitats to survive. Now, river meadow species have been shaded out by swamp forests or out-competed by dominant, often non-native species. Surprisingly, though, the habitats we examined lost similar proportions of species, despite very different changes in the land area each habitat covers—e.g., rapid declines in grass-

land areas and expansion of forests—suggesting that habitat loss was not the only or even most important factor driving species loss. Perhaps wildflower flowers were especially abundant during Thoreau's time because hunting had eliminated deer. When deer returned during recent decades (Foster, 2002), they presumably eliminated many succulent wildflowers, particularly members of the orchid and lily families (Rooney, 2001).

The development-related pressures in Concord include habitat fragmentation, air and water pollution, acid rain, nitrogen deposition, habitat destruction, introduced species, and heavy recreational use. All of these factors have well-documented, often negative effects on biodiversity (Laurance and Cochrane, 2001; Lienert et al., 2002; MEA, 2005; Stehlik et al., 2007). In Concord, the construction of housing and other buildings from the 1940s onward destroyed the locations of certain rare species (Eaton, 1974). The increasing dominance of invasive plants may be related to increasing levels of nitrogen deposition, increased CO₂, soil disturbance during development and other human activities, and tolerance of deer grazing (Facon et al., 2006). Changing patterns of temperature and precipitation associated with climate change may also be contributing to the decline and loss of native species in Concord and elsewhere (Willis et al., 2008). Other studies of conservation areas, towns and cities in Massachusetts have recorded greater or lesser losses of species, according to each location's land use history and each study's sampling design and time period (Drayton and Primack, 1996; Bertin, 2002; Standley, 2003). In comparable European studies, agricultural intensification has been identified as a major factor that changes the relative abundance and presence of species (McCollin et al., 2000; Van der Veken et al., 2004).

Rare species make up a large portion of the current Concord flora. Of 589 species currently present, 150 species (25% of the current flora) are now rare. Further, 15 of these species are extremely rare, with only one individual present, and 37 species are very rare, with between two and 10 plants. Our research and other studies show that past abundance is a good predictor of the survival probability of a species (Fischer and Stöcklin, 1997; Lavergne et al., 2006; Walker and Preston, 2006). Because 25% of the species are now rare (single population) and 28% of the species are infrequent (two populations), 53% of the current flora is in danger of local extinction.

What is the likely time frame of this impending loss of species? Depending on the method of extrapolation, projections of future losses vary. If we assume that rates of extinction continue just as they have over the past three to four decades, then around 175 species (30% of the flora) will be lost in the next few decades. If we assume that the rates continue as they have over the past 100 years, then 145–163 species (25–28% of the flora) will be lost in the next 100 years. If we assume that rates of extinction continue for just the rare species, then approximately 156 species (50% of the rare and infrequent species) will disappear in the next 30–40 years. These rates of loss may change depending on management practices, plant conservation efforts, land development and the size of the human population. However, regardless of which scenario is used, large numbers of Concord's native plants species, those that Thoreau observed and wrote about, are in danger of local extinction in the coming decades.

Land protection is often the first step toward conserving species. Already 35% of Concord's area is under protection, and plans exist for further land protection (Concord, 2005). However, even when land is protected, the combined forces of forest succession, habitat fragmentation, invasive species, deer, air and water pollution, and other factors can eliminate native species over time. Land has been actively managed in Concord in various places to maintain create open habitats, mainly for aesthetic purposes and for wildlife. River meadows are maintained by mowing at the Old Calf Pasture and Minute Man National Historical Park. At these sites, many rare wildflower species have persisted and perhaps have even re-established themselves from buried seeds or dormant plants. Meadows are maintained by the town of Concord and by various conservation organizations.

Of 80 native rare species in Concord, 45 of them occur on land that is managed in some way. Many of the species that occur on unprotected lands grow along roadsides and probably need the disturbance and light that these habitats provide. Managed habitats occupy only a small percent of Concord's total area as seen in Fig. 1. Most notable are places such as Walden Pond, Minute Man National Historical Park, the Old Calf Pasture, and the Landfill. In addition to active mowing of meadows, much of the management that encourages rare species at places such as Walden Pond is simply maintaining trails and open areas around buildings and walls. If these management efforts were to stop, many rare, native species would probably be eliminated within a few years. Additionally, the results of Pratt's experiment, even though he used non-native species, suggest that re-establishing these lost wildflower species would have a low probability of success.

If Thoreau were alive today, he would note radical changes in the Concord landscape, particularly the greater area of forest and corresponding decrease of open meadows. He would also notice many familiar plants, but would wonder where other species had gone. Perhaps we should remember his comment from the beginning of the paper:

I take infinite pains to know all of the phenomena of the spring, ... and then to my chagrin, I hear that it is but an imperfect copy that I possess... (Thoreau's Journals, March 23, 1856)

The efforts of a wide variety of conservation organizations may have slowed the loss of species, but a large portion of Concord's flora has already been lost. More of Concord's plant species will disappear unless existing management plans are continued and new plans are implemented. Better coordination among the various landowners would facilitate the protection of species diversity. Without such efforts, future readers of Thoreau's books may wander the conservation lands looking in vain for the orchids, lilies, and other wildflowers that helped to inspire his environmental vision.

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